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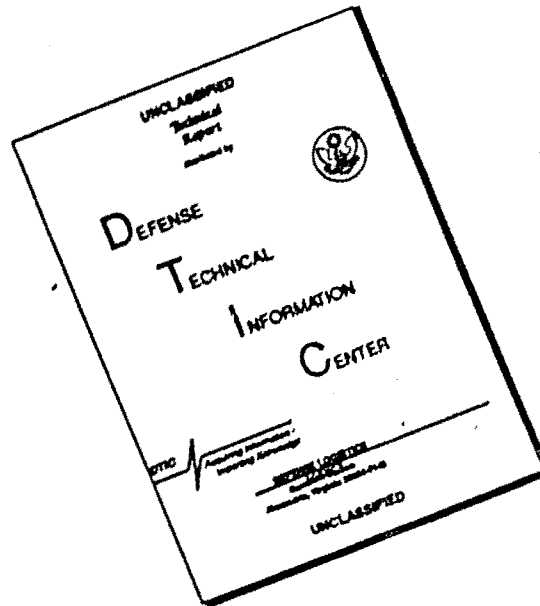
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ROCK ISLAND ARSENAL
RESEARCH & DEVELOPMENT DIVISION
DESIGN ENGINEERING BRANCH



TECHNICAL REPORT

GROUND ANCHOR DEVICES
AND INVESTIGATIONS OF ANCHORING APPROACHES
FOR TEMPERATE AND ARCTIC REGIONS

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AUTHOR OWEN W. MARLOW

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GROUND ANCHOR DEVICES
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Rock Island Arsenal
Rock Island, Illinois

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ABSTRACT

This report outlines the principal approaches tested and/or evaluated for emplacement of anchoring devices for rocket launcher and artillery carriages. Part I of this report deals largely with the Anchorage problem of rocket launchers in hard frozen ground. Part II covers the investigation of stability problems of firing platforms for conventional cannon-type artillery weapons in temperate climates. Critical anchoring problems in both Arctic and temperate climates exist for both types of weapons.

Ground Anchor Devices
and Investigations of Anchoring Approaches
for Temperate and Arctic Regions

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INTRODUCTION

With military operations becoming world wide in scope, the anchoring of weapons and military equipment in all sorts of terrain from loose sand to hard frozen ground became a major problem. In search of a solution to the specific problem of Artillery Gun and Rocket Launcher Anchorage, this Arsenal has made substantial study. The following account is given to show the direction, difficulties encountered and the successes so far attained.

SUMMARY

The investigation of the anchoring problem applying to rocket launchers as it relates to frozen ground covers quite a wide field. Some approaches were abandoned after very limited study when their promise of success appeared not to warrant the expenditure of the needed time and funds. Some of these did not warrant inclusion in this report. Those having unusual or significant features have been included in the findings. The "jet perforator" shaped charge has so far shown the greatest promise. It is being included in the initial kits to be released to the user for evaluation. Further evaluation and/or development of the jet perforator and possibly further investigation of some other approaches appears warranted.

Stability problems in the anchoring of 360° traverse artillery weapons in average soils under temperate conditions are quite complex. Bearing values of most soils are too low to absorb the forces generated during gun firing on the surfaces of anchoring devices available within the specified weight limitations. Raising the allowable bearing value of the soil by chemical treatment or other means may be necessary to keep within acceptable weight limits for weapon and accessories.

CONCLUSIONS

The investigation and testing of a large number of items and approaches resulted in the following conclusions on the anchoring in frozen ground problem:

1. Hand Sledge. The hand sledge is the basic tool of the present system; by itself, it is inadequate. Its effectiveness may be multiplied when used in conjunction with other equipment.

2. Rotary Drill (Powered). The power source for the rotary drill is a gasoline engine. The unit has portability characteristics which permit one man handling and operation. The theoretical principle was considered to have sufficient merit to undertake procurement of a model for tests.

3. Impact Drill. The impact drill principle was considered to have good possibilities for successful application to the kit. A test program to establish the feasibility of the principle was urged. The choice of a power source was as follows:

- a. Gasoline Powered
- b. Pneumatic
- c. Electric
- d. Cartridge Actuated

4. Rocket Emplacement of Stakes. The principle of rocket implanting of stakes appears to justify further study -- this principle has been used in other applications with development and test programs in process. Decision was made to support a program of tests of this approach.

5. Hand Auger. The slow progress of a hand rotated auger, discouraged further consideration.

6. Shaped Charge (Lancing of pilot hole for stake insertion). The development of a pilot hole by use of explosives was considered a good possibility. The pilot probe would permit either manual or machine driving of the stake. The decision was made to pursue this method further. Information extracted from Technical Report 45, April 1957, by Snow, Ice and Permafrost Research Establishment, Corps of Engineers, U. S. Army, on tests made at Ft. Churchill, Manitoba; encouraged investigation of this approach. Support of a program of tests was decided upon.

7. Vacuum Plate. The weight and complication of the equipment connected with this type of anchoring, discouraged further consideration.

8. Heated Stakes. The approach was rejected on the basis of the excessive burden of support equipment necessary to make it workable.

9. Sonic Conditioning. This approach was highly theoretical, the idea advanced a theory of employing sonic waves to pre-condition soils to a condition which would permit driving of stakes by conventional methods. The equipment

and source of power would present a problem, and its effectiveness was in doubt. The approach was rejected.

10. Arctic Adapter, Drive Pickets. The equipment consists of a metal baseplate nailed to the earth with steel pins or spikes. To provide sufficient holding power for the purpose intended, six to eight pins would be required. Emplacement is accomplished with a drive sleeve and pin. A sample arrangement was built and tested. The results were not sufficiently encouraging to pursue it further. Difficulty was foreseen where emplacement is necessary on a partially thawed surface. The spikes would not have sufficient penetration in the solid material to provide secure anchorage.

11. Ground Anchors. The anchor unit consists of an arrow shaped device which is driven to a depth of approximately three (3) feet with a rod which is removed after the anchor has been driven to the desired depth. A wire attachment protrudes above the ground surface for attachment of a chain or cable. The problem of frozen soil penetration is not solved by this application.

RECOMMENDATIONS

It is recommended that further development and evaluation of the jet perforator shaped charge to determine and improve its limits safety-wise and prescribe procedures for tactical use by troops. It is also recommended that an investigation of the use of a closed-breech gun type of soil perforator be considered as an alternate back up of the jet perforator.

OBJECTIVE

The objective of the study is to develop an Arctic Anchorage emplacement device, or devices and procedures for consolidation into the Littlejohn Rocket System. A successful development in this area would have a broad range of application in the anchored emplacement of weapons, shelters and other erections in the Arctic and sub-Arctic environments. Anchoring of weapons in normal and soft soils for sustained periods of firing is a desired development. Artillery weapons with 360° traverse presents problems requiring departure from previous procedures in anchoring.

HISTORY

The Rock Island Arsenal, Special Equipment Section's concern with the problem on a project basis dates from August 1959. The Air Force and branches of the Army concerned with the problem, have given their attention to its solution. As far as is known, no effective method without elaborate support equipment, has resulted. Much of the Rock Island Arsenal effort has been directed toward a "searching out" of the military and civil background of the problem; attempting to combine available equipment and tried techniques in an agile solution. However, the investigation has not been restricted to this procedure. The enlarged study established communication with organizations, Government and private, with a declared interest in the field of inquiry. Proposals and suggestions were tendered in response to search inquiries and to formal Request for Proposal. Artillery Weapons Anchoring studies cover an extended period of time and involve investigations by both Government and private agencies.

PROCEDURE AND RESULTS, Part I

The investigation of possible approaches for emplanting anchors in hard frozen soils involved a number of types of equipment at a number of locations and conditions by a plurality of agencies and firms. The general procedure followed and results obtained are in most instances listed in connection with reporting on the portion of tests conducted by the various agencies as given below:

EQUIPMENT FOR TEST

1. Selection. The selection of equipment for preliminary test was based on the tentative evaluations as outlined in conclusions. The stake emplacing devices and techniques considered for test at this time may be placed in two broad groupings as follows:

a. Direct Stake Driving

- (1) Impact Hammer
- (2) Rocket Driven Stake
- (3) Manual Stake Driving

b. Stake Driven in Pilot Hole

Pilot Hole developed by:

- (1) Rotary Drilling
- (2) Impact Drilling
- (3) Explosive Charge

2. Impact Hammers

a. Gasoline Hammer

- (1) Two commercially available gasoline hammer units by different manufacturers were used in the tests. The operating principle is basically that of a 2 cycle internal combustion engine. The handling characteristics are those of the pneumatic hammer. One of the units required an external electrical source for ignition, the other was fully self-sustained. Early tests were intended to demonstrate the feasibility of the impact hammer principle rather than the relative merits of the two hammers.

- (2) For Direct Stake-Driving operation, the hammer was fitted with an adapter to accept the pilot pin on the special power driven stake. For making a pre-bored pilot hole, a stardrill or concrete-breaker attachment is employed, these were furnished with the machine.

b. Electric Hammer Drill. The electric hammer drill provides impact or vibration with rotation. The unit is made for use as a concrete breaker. The number of blows per minute varies somewhat with the size of the unit, it is usually in the range of 1800 to 2000 impulses per minute for a size using a 1-1/2 to 2 inch diameter drill tool. This device was applied to the pre-bored hole option for stake emplacement. The electric hammer requires an external source of electrical energy.

c. Pneumatic Hammer. The pneumatic hammer is a familiar common place tool and requires little discussion. It is applicable without modification, with tools furnished for pre-drilling holes for stake insertion. The pneumatic hammer requires an external source of compressed air.

3. Rocket Driven Stakes.

a. The theory of driving stakes by rocket power is based on the theory of penetration of solid objects by low velocity projectiles. The penetration of the target material is directly proportional to the Kinetic Energy developed.

b. The rocket propelled stake has provision for the attachment of a small rocket motor. The stake and attached rocket is fired from a tripod supported tubular launcher. Adjustments are provided for stand-off and tilt. Firing is electrical, from a remote position. Two types of rocket powered stakes were provided in the system under discussion.

c. The first, a stake designed primarily for Arctic use, was of a cruciform cross section, 21-5/8 inches in length, and weighing approximately 4 pounds. The other stake option, provided an explosive head to expand the stake, once it was inserted in the ground. The peeling action splits the end of the anchor body into six (6) prongs which engage the surrounding earth mass for a secure anchorage. This stake finds use primarily in soft and unfrozen ground. The anchor stake is provided with a threaded extension carrying spoiler nuts and washer.

4. Manual Stake Driving. The manual insertion of stakes or anchors requires little discussion, it is mentioned here as an auxiliary which may complement a more sophisticated technique. The equipment will consist of a standard sledge and conventional stakes. A standard sledge would be a 12 to 16 pound designation.

5. Rotary Drilling. The rotary drilling device had as its prime power source, a two cycle internal combustion engine with an integral speed reducer to the output shaft. Driving of the vertical output shaft is through a centrifugal clutch operating in response to engine speed. Drills were designed and built for application to this unit. The unit possesses a high degree of portability, readily handled and operated by one man. It is fully self sustained in operation. Its intended use in the Arctic Kit, was for pre-boring a hole for stake insertion.

6. Shaped Charge.

a. The shaped charge is an explosive charge which is so shaped as to concentrate a large portion of its released energy in a small area. When the charge is fired, a detonation wave sweeps from the apex to the base along a conical liner, collapsing the liner into a small diameter jet moving at a velocity of from 6000 to 30,000 feet per second, and a metallic slug moving at a lesser velocity of 1500 to 3000 feet per second. When the high velocity jet impinges on a solid target, it produces pressures greatly in excess of the yield strength of the material, forcing the target material to flow plastically out of its path to form a tubular hole.

b. The charge tested is a commercially available explosive, designated as a "Jet Perforator." A physical equivalent is the "Jet Tapper," finding a use in the tapping of Open Hearth steel furnaces. The "Jet Perforator" consists of a copper cone 1-3/4 inches in diameter with an 80 degree included angle, the explosive charge is waxed RDX encased in a plastic shell. Provisions for the insertion of a blasting cap is made in the hollow cylindrical neck of the case; the neck base contains a straight RDX primer charge.

c. A complete shaped charge assembly for test purposes, consists of:

- (1) Shaped Charge Head
- (2) Electric Blasting Cap with leads
- (3) Blasting Machine

- (4) Stand-off Cone (Hard Cardboard)
- (5) Perforated cardboard strip (for mounting charge to stand-off)
- (6) Tape (special for Arctic use, pressure sensitive -- for mounting strip to charge head)

7. Miscellaneous Equipment

a. Drills. Drills used in the rotary drilling sequence were made up at Rock Island Arsenal, the carboloy tipped auger; 1-3/4 inches in diameter, was coated with an epoxy resin. Early studies made note of a tendency for the drill to become clogged when penetrating cohesive soils, the epoxy coating was applied as a preventative.

b. Stakes. The stakes used in tests were of two general types, their design was largely influenced by the method of emplacement. They are described as follows:

(1) Sledge Driven Stake. The standard sledge driven stake is of 120° Y cross section, twenty inches in length, and coated with epoxy resin.

(2) Power Adapted Stake. The machine driven stake is of 120° Y cross section, epoxy coated, and seventeen inches in length.

LOCAL TEST (ROCK ISLAND ARSENAL PRELIMINARY STUDY)

1. Purpose. The preliminary test was undertaken to:

- a. Verify the theoretical evaluations.
- b. Compare the relative merits of two approaches to frozen ground penetration (Impact Drill and Rotary Drill).
- c. Study the feasibility of direct stake emplacement with power tools.

2. Test Preparation. Due to difficulties in venting the Laboratory cold room, it was decided that testing should be conducted out of doors. The soil samples were to be conditioned at a temperature of -65°F. for a period of one week and removed from the cold room just prior to the test. Samples of four different soil combinations were prepared and placed in a box of four sections. The overall dimensions of the box were 4 feet x 4 feet x 1-1/2 feet. Each section containing approximately 6 cubic feet

of soil mixture. The soil compositions were as follows:

- a. Six (6) cubic feet river sand
- b. Six (6) cubic feet red clay
- c. 66% red clay, 27% river sand, 7% pea gravel
- d. 60% pea gravel, 20% river sand, 20% red clay

Note. The soil samples were saturated with water prior to their low temperature conditioning.

3. Procedure and Results. The plan for testing required the removal of the earth samples from the cold chamber. Testing was to be conducted at out door ambients. The machines for test were to be started and operated at ambient temperature. Allowance was made for preliminary "warmup" before attempting power drilling or staking.

a. Rotary Drilling. The rotary device (Unit #1), using a Rock Island Arsenal manufactured carboloy tipped auger, produced a hole 14 inches deep in approximately 5 minutes. A second hole 12 inches in depth was made in 6 minutes. The holes were drilled in frozen clay, soaked at -65° F. for several days. The increase in time and decrease in drilling efficiency on the second trial is attributed to the dulling of the cutting edges. Examination of the auger revealed chipping of the carboloy tips.

b. Gasoline Powered Hammers. Two gasoline hammers of different manufacture were employed to demonstrate the two options of stake emplacement (Units #2 and #3).

(1) Prebored holes for the insertion

(2) Direct Stake Driving

The hammer operation converted much of the energy expended to heat. As the tool penetrated the frozen earth mud was extruded around the tool, causing some difficulty in withdrawing the tool from the boring. This was not a problem in the direct stake driving, (except when the engine stopped or the operation was halted for any reason short of completion), the extruded material promptly froze, welding the stake to the frozen earth. The stakes so emplaced were considered expendable. The performance data for the three units is tabulated in Table #1.

- (2) The Stardrill used in the frozen clay was damaged in trial #7. After penetration to a depth of from 2-1/2 to 3 inches, refreezing of the extruded material at the surface was noted. In attempting to withdraw the tool from the boring, the tip was separated from the shank. It was necessary to dig the tip out of the frozen clay, using a concrete breaker attachment to the hammer. In other tests the gasoline hammer drove stakes in frozen clay to a depth of 10 inches in 5 minutes. In frozen gravel a depth of 5-1/2 inches was attained in 5 minutes.

TABLE I

Trial Number	Operation	Penetration Inches	Time Min.	Type Soil	Unit No.
1	Hole Drilling	14	5	Clay	1
	"	12	6	"	1
	Stake Driving	15	5	"	1
	Prebore Hole	9-10	2-1/2	"	2
	"	9-10	5	Gravel	3
	"	3-4	4-3/4	"	3
	(Stardrill)	2-1/2 -3	1-1/2	Clay	3
	Stake Driving	14	5-1/2	"	2

For Trial #7 - Drill Damaged

- Electric Hammers. Representatives of a manufacturer of electric hammer drill demonstrated their product under Island Arsenal supervision. This test was conducted at the Rock Island Laboratory cold chamber, the results tabulated in Table II.

TABLE II

Operation	*Penetration Inches	Time Min.	Type Soil
Hole Drilling	5-1/2 -6	3.23	Gravel
"	"	1.6	Clay
"	"	3.29	Gravel

It was noticed by the length of the drills that progress at greater depth would be at a

4. Discussion, Local Test Results.

a. The results of the rotary drill study, indicates that the abrasive characteristics of frozen soil will limit the useful life of the auger. Replacement and maintenance of the tool, are requirements which would make its adoption untenable in a tactical system. The probable performance of this approach does not appear to warrant further study.

b. The impact hammer was considered to be worthy of further consideration. The low level of reliability and starting difficulties, discourage the adoption of a 2 cycle engine as the prime source of power.

c. The electric hammer test was inconclusive; however, the results were not considered inconsistent with the observed performance of the gasoline powered units and, therefore, may serve to reinforce this data in any subsequent evaluation of the impact hammer principle. The external power source required for the electric unit, presents an obstacle to its integration in a high mobility system.

EGLIN AIR FORCE BASE TESTS

1. General.

The Eglin Air Force Base Tests were conducted in August 1960.

The soil used for tests was saturated with water and conditioned for 60 hours at -65° F. prior to the stake driving trials.

The Pionjar gasoline powered hammer, one of the type and manufacture, tested previously, at Rock Island Arsenal (Unit #3), was employed as the prime stake driver.

2. Procedure and Results.

a. Stake driving was performed on two soil samples, designated as type A and B.

- (1) Soil Type A consisted of a 6 inch depth of sand over a 12 inch depth of dirt and gravel.
- (2) Soil Type B was a 6 inch layer of sand over 6 inches of gravel.
- (3) Four stakes were driven with the gasoline hammer; three stakes were driven to a depth of 6-1/2 inches and a fourth to a depth of 8 inches. The results are tabulated in Table III.

TABLE III

Trial Nr.	Soil Temp(°F)	Stake Penetration	Time Minutes	Soil Type	Remarks
1	-65	6-3/4	2	A	Stake could be driven no further. Stake broke.
2	-65	6-1/2	2	A	Stake could be driven no further. Pilot Pin broke off.
3	-65	6-1/2	3	B	Stake could be driven no further.
4	-65	8	5	B	Stake could be driven no further.

3. Discussion of Results. The test findings are not in conflict with those of the Rock Island Arsenal study. Appraised within the experience background to date, the impact hammer application, is considered to possess some merit as a stake driving technique. Improvement in equipment and the adoption of a more reliable source of power are necessary for operation in the Arctic.

ARGMA TESTS ("Jet Perforator" Shaped Charge and Gasoline Hammer)

1. General. The tests of the "Jet Perforator" shaped charges were conducted by the Army Rocket and Guided Missile Agency Test and Evaluation Laboratory at the request of Rock Island Arsenal. Additional comparative tests between the gasoline hammer and the sledge hammer were made to evaluate their relative effectiveness in driving an anchor into the pilot holes made by the "Jet Perforator." The gasoline hammer with power adapter was the same as that employed in the tests conducted at Eglin Air Force Base, previously discussed.

2. Purpose. The primary objective of these trials was to determine the suitability of the "Jet Perforator" as an aid in emplacing stakes in Arctic regions. Secondary objectives are described as:

a. To determine the effects of accidental mishandling on the performance and handling safety of the explosive charges.

b. To observe the influence of soil temperature on jet perforator performance.

c. Note the effect of soil type on jet penetration.

d. Determine suitability for use on terrain consisting of total rock or ice.

e. Record the influence of varying stand-off distances on "Jet" penetration.

f. Make a comparison of performance between hand sledge driving and power driving of stakes into the pilot holes.

g. Observe and record the missile effect arising from the explosion.

3. Test Procedure.

a. Three soil types, designated A, B, and C were prepared for test observation. Their composition by volume was as follows:

Type A - River Sand 25%, Red Clay 62.5% and Fine Gravel 12.5%

Type B - Red Clay 100%

Type C - River Sand 20%, Red Clay 20%, Fine Gravel 10% and Coarse Gravel 50%

The soil samples were placed in containers saturated with water, and conditioned. Five containers were used; quantity and conditioning was as follows:

Type A - 1 Container @ + 28° F.
 1 " @ - 20° F.
 1 " @ - 60° F.

Type B - 1 " @ - 20° F.

Type C - 1 " @ - 20° F.

b. The equipment used in the test, gasoline hammer, "Jet Perforator" charge, and staking equipment are described under EQUIPMENT FOR TEST (page 5). Eighteen charges were fired; of these, eight were subjected to drop tests. The following firing and test procedures were used:

- (1) Soil container and charge were removed from conditioning.
- (2) Charge fired.
- (3) Depth and diameter of hole measured (at various depths).
- (4) A stake is emplaced in the pilot hole. (Power or sledge driven)
- (5) Another charge is obtained from conditioning, and the firing and stake insertion procedures are repeated until the required number of trials are performed on the sample.
- (6) Another soil sample is removed from conditioning and the described procedures are repeated.

4. Discussion of Results.

a. Drop Test. Eight "Jet Perforator" charges encased in their heat insulating plaster containers were dropped from a height of eight feet onto a solid concrete floor without exploding. No external damage was noted and X-rays revealed no internal damage. The charges were later fired without any impairment to their performance.

b. Influence of Soil Temperature. The explosive charges were conditioned at the same temperature as the target material. The results of the firings indicated that depth and volume of jet penetration increased with temperature. Although the pilot hole profiles were smaller at -60° F. than at -20° F., the time needed to drive the stakes to

comparable depths was not significantly different. The pilot hole profile made by the charge fired into the +28° F. target was too large to be useful for stake holding purposes.

c. Soil Type. The soil type did not have an appreciable effect on the pilot hole profile. A significant difference in stake driving time was noted. A longer time was required to drive a stake in soil Type C (with a high gravel content) than was needed to drive a stake to the same depth in soils Type A or B.

d. Ice. One charge was fired into a block of ice conditioned at -60° F. The surface of the block was shattered, a large portion of the ice block melted without developing a useable pilot hole.

e. Rock. One charge was expended on sandstone. A probe 9-1/2 inches in depth and 1 inch in diameter at the inlet was formed. The stakes used in the test were not compatible with the profile.

f. Influence of Stand-Off Distance. One charge in the program was fired at a stand-off of 11-1/2 inches. All others were fired from a 3-1/2 inch stand-off. A single trial at this stand-off cannot be cited as an indicator of performance, although some confirmation of the shaped charge theory may be inferred. Its penetration in Type A soil, conditioned at -60° F., was 21-3/4 inches, the deepest penetration of a target conditioned at this temperature. The volume however, was less than the volume of 60% of the probes made in targets of this temperature.

g. Sledge versus Gasoline Hammer. The sledge hammer compared favorably with the gasoline hammer as a stake driving tool. A direct comparison may be made on pilot holes of like profile as tabulated in Table IV. Taking into consideration the profile of the pilot hole, displacement, soil composition, and soil temperature, no wide divergency in performance is noted. A more comprehensive study is required to compare the two driving methods.

h. Missile Effect. Celotex witness screens were positioned around and over the firing site to obtain some measure of the missile hazard. Fragments from the plastic case of the charge, as well as rock fragments, were noted imbedded in the witness screens as far as ten feet from the blast. Screens placed over the firing site were riddled slightly with gravel, penetrations were minor, usually less than 1/8 inch. Further testing with emphasis on the missile distribution is indicated.

TABLE IV

Trial Nr.	Soil Type	Soil Temp °F.	*Dis- place- ment in.	Ent. Dia.	Stake Type	Hammer Type	Depth of Stake Penetration (In.) (Time in Seconds)									
							6	7	8	9	10	11	12	13	14	15
2 ¹	C	-20	8.66	1-3/4	Power Adapted	Power	33		75	101	120	141	160	180	202	207
18 ²	C	-20	9.65	1-3/4	Std LJ	Sledge		20	37	52	70					
14 ³	B	-20	6.43	1-1/2	Power Adapted	Power			40							
15 ⁴	B	-20	5.07	1-1/2	Std LJ	Sledge			15	20		30	50			
10 ⁵	A	-60	4.57	1-1/4	Std LJ	Sledge	10	20	32	42	53					
7 ⁶	A	-60	4.32	1-1/8	Power Adapted	Power	11	22	30	40	65	90	115			
20 ⁶	A	-60	3.89	1-3/8	Power Adapted	Power	9	21	35	53	90	105	125			
1 ⁷	A	-60	3.27	1.	Power Adapted	Power	15	50								

* Displacement is approximate volume (cu. in.³) to a depth of 8 inches.

1. Stake Driven to hilt
2. Stake could not be driven beyond the 10 inch depth
3. Stake could not be driven beyond the 8 inch depth
4. Ground cracked under impact of sledge
5. Stake could have been driven deeper
6. Maximum depth reached - 12 inches
7. Stake could not be driven beyond the 7 inch depth

5. Conclusions.

a. The "Jet Perforator" shaped charge is a suitable aid for driving stakes in Arctic regions.

b. A more comprehensive discussion of this test is contained in the R&D Test Report, 21 Nov 1960, entitled Preliminary Evaluation of Jet Perforator for Little John Launcher Anchoring in Arctic Regions, Project TU2-1038, Test and Evaluation Laboratory, Army Rocket and Guided Missile Agency.

TEST OF ROCKET DRIVEN STAKES (Rock Island Arsenal Test)

1. General.

a. The test of the Rocket Driven Staking equipment and technique, was primarily directed to the anchoring of Artillery Weapons. However, the problem of Arctic Anchoring, and its solution is of common interest to all weapon systems. In this instance, the development of a suitable method, could be profitably shared.

b. The equipment used in this test is described on page 5.

2. Purpose. The purpose of the test is to determine the depths of stake penetration in frozen and unfrozen ground and the maximum horizontal and vertical loading sustained by the implanted anchors.

3. Test Procedure and Results. A soil consisting of a moist sandy loam, at the Rock Island Arsenal Proving Ground, was the target medium. The area was free of rocks and shell fragments. Selected areas were divested of their grass cover, marked and frozen by an application of dry ice to the surface. The designated areas were maintained in their frozen condition for the duration of the test program. The stakes were driven in accordance with the planned procedure. Stake penetration, ground temperature, and stake loadings are tabulated in Table V.

Stake number 9 was the only stake driven in unfrozen soil. The failure of stakes numbers 7 and 8 to anchor properly is attributed to the brittle fracture of the frozen target.

4. Comment.

a. The results of the RIA test demonstrates the suitability of the rocket driven stakes to Arctic operations.

b. The rocket driven anchor is a candidate for further testing in the Arctic.

c. Further information on the test is contained in Report No. 61-1247, dated 28 March 1961: Test of Rocket Driven Stakes, Rock Island Arsenal Laboratory.

TABLE V

Stake No.	Type	Grnd Temp °F		Depth of Stake Penetration(")	Horizontal Load (lbs)	Loading & Temp		24 Hrs After Driving	
		at 6"	24"			Grnd Temp at 6"	24"	Horizontal Load (lbs)	Vertical Load(lbs)
1	Arctic Anchor	-70	-24	8-1/2	1400	-97	-37	--	2400
2	Arctic Anchor	-70	-24	10	5900	-97	-37	15,500	--
3	Arctic Anchor	-70	-24	12	5200	-97	-37	1,525	--
4	Arctic Anchor	-70	-24	13-1/2	1400	-97	-37	*8,750	225
5	Explosive Hd (Deactivated)	-97	-37	9	5500	-97	-37	10,000	--
6	Arctic Anchor	-70	-24	25	--	-97	-37	--	13,000
7	Explosive Hd	-70	-24	6 failed	--	-97	-37	--	--
8	Explosive Hd	-70	-24	6 failed	--	-97	-37	--	--
9	Explosive Hd	+34	40	54	--	36	40	--	1,250

* Horizontal Load Applied First

ARCTIC TESTS

1. General. In the absence of complete and official results at the date of this writing, only a cursory discussion of the Arctic Test Program is possible. The test period extended from December 1960 to April 1961.
2. Purpose. The objectives of the Arctic test program was to substantiate or rebut the findings of earlier studies and tests in assumed or synthesized environments. The conditions surrounding the Arctic tests were those of the day to day ambients and the natural terrain conditions that existed during the test period.
3. Test Procedure and Results. Three stake driving methods were studied during the 1960-61 Arctic test period:
 - a. Gasoline driven hammer (direct stake driving)
 - b. Rocket driven stakes
 - c. Sledge driven stakes in pilot holes developed by shaped charge explosives

Tests of the gasoline hammer were limited due to mechanical failure. Only three stakes were emplaced by this method.

It was found that the 120° "Y-stakes" tended to be loose in the ground after driving with the gasoline hammer; one was pulled from the ground manually. The round bar stake (special design, adapted to machine driving), driven by the gasoline hammer, was secure and could not be removed. The time required to drive the stakes, averaged 2.25 minutes at an ambient temperature of 26° F. A sampling of the test results of the rocket driven stakes and the sledge driven stakes (Driven in "Jet Perforator" pilot holes), are tabulated in Table VI. This is not a complete tabulation of the results. The trials described were all made at sub zero ambients and are a fair sampling of these conditions. The rocket stakes were of the same type and manufacture as the Arctic stakes previously discussed in Rock Island Arsenal Laboratory tests.

4. Conclusions.

- a. Gasoline Hammer. The weight, size, and maintenance requirements of the gasoline hammer defeats its employment as an Arctic Stake Driver.

TABLE VI

Stake No.	Date	Temp °F.	Type of Soil	Method of Driving	Pilot Hole Depth			Stake Pen Depth (Inches)	Time to Drive	Remarks
					1/4"	1/2"	1"			
3	19 Dec 60	-5	Sand & Gravel	Sledge	6-1/2	5	4	7-1/2	35 sec.	3-1/2" Stand-off
4	19 Dec 60		"	Sledge	3	1	1-1/2	12	45 sec.	10-1/2" Stand-off
5	9 Jan 61	-21	Clay & Gravel	Sledge	13	11	4-1/2	12	30 sec.	3-1/2" Stand-off
6	9 Jan 61	-21	"	Sledge	13	13-1/2	4-1/2	12	30 sec.	3-1/2" Stand-off
7	9 Jan 61	-21	"	-----	--	--	-	--	--	No hole-blown over w/sand
8	9 Jan 61	-21	"	Rocket	--	--	-	12	--	
9	9 Jan 61	-21	"	Rocket	--	--	-	12	--	
10	16 Jan 61	-19	"	Rocket	--	--	-	10	60 sec.	
11	16 Jan 61	-19	"	Sledge	22	10	4-1/2	14	60 sec.	3-1/2" Stand-off
12	16 Jan 61	-19	"	Sledge	20	9	4-1/2	11	46 sec.	3-1/2" Stand-off
19	5 Mar 61	-39	"	Sledge	19-1/2	17-1/2	4	11	33 sec.	3-1/2" Stand-off
20	5 Mar 61	-39	"	Sledge	22	18-1/2	4-1/2	12	36 sec.	3-1/2" Stand-off
21	5 Mar 61	-39	"	Sledge	21	16	4	12	37 sec.	3-1/2" Stand-off
22	5 Mar 61	-39	"	Sledge	19-1/2	17	5	13	40 sec.	3-1/2" Stand-off
23	7 Mar 61	-37	Sand & Gravel	Rocket	--	--	-	14	--	Rkt motor stuck in launcher
24	7 Mar 61	-37	"	Rocket	--	--	-	15	--	
25	7 Mar 61	-37	"	Rocket	--	--	-	15	--	
26	7 Mar 61	-37	"	Rocket	--	--	-	18	--	

b. Rocket Driven Stakes. Seventeen rocket driven stakes were used in two types of soils, the level of performance in each soil type may be described in terms of average penetration:

<u>Soil Type</u>	<u>Average Penetration (inches)</u>
Sand and Gravel	13
Clay and Gravel	12.3

Although the launcher is light in weight, its length (7.5 ft.) made it difficult to handle. The test launcher was vulnerable to damage in ordinary handling. The muzzle end became dented, causing difficulty in disengaging it from the rocket motor. Approximately three minutes are required to set up, load, and fire a round.

Because of the size of the launcher, its sensitivity to damage, and the length of time required to fire four stakes, this system is not recommended for use with the tactical Littlejohn System.

c. Shaped Charge Developed Pilot Hole.

(1) Twenty stakes were driven in pilot holes made by the "Jet Perforator" shaped charge. Two stand-off distances were used in setting the charge: 3-1/2 and 10-1/2 inches. The average depth of the pilot hole, hole diameter, stake penetration, and stake driving time is as tabulated.

Stand-off (in.)	Hole Dia. (in.)	Depth (in.)	Stake Penetration (in.)	Driving Time (Sec.)
a. 3-1/2	1/4	17.7	12.9	40
b. 10-1/2	1/4	11.5	12.9	40

- (2) The time required to set the charge was approximately 5 minutes for 4 charges. All four charges were blown at the same time with a blasting machine.
- (3) The compactness, simplicity, and the absence of maintenance requirements, makes the shaped charge approach superior to any of those tested.
- (4) The reported results, discussion, and tentative conclusions are, in substance, those of the U. S. Army Arctic Test Board.

PROCEDURE AND RESULTS, Part II

The investigation of firing platform stability for weapons with 360° off-carriage traverse was based on General and Specific Requirements furnished by higher authority.

GENERAL REQUIREMENTS

The firing base shall be designed to serve as a pivot, which will provide the weapon with 360° off-carriage traverse, and as an anchor for absorbing the weapon's recoil force. The weapon shall be capable of performing these functions in a wide variety of soils with a minimum amount of effort expended on the emplacement and displacement of the platform, and a minimum amount of accessory equipment.

SPECIFIC REQUIREMENTS

1. The force levels which the platform shall resist are to be in the range of 12,000 to 40,000 pounds at 0° elevation and 14,000 to 70,000 pounds at 40° to 65° elevation.
2. The firing platform shall be stable at all angles of elevation (0° to 65°) and traverse 360°.
3. It is desired that the firing platform shall be stable without the use of stakes.
4. It is desired that digging of an emplacement for the platform shall not be required.
5. 360° off-carriage traverse about the firing platform, permitting rapid shifts of the field of fire (1 minute) outside the limits of normal on-carriage traverse, shall be incorporated in the design.
6. The platform shall be capable of rapid emplacement and displacement with a limited amount of manpower.
7. Vertical and horizontal movements after a large number of rounds (50 rounds) shall be negligible (vertical movement - 2 inches, horizontal movement - 6 inches).
8. The overall weight of the platform shall be a minimum weight commensurate with the requirements of the system.

PLATFORM DEVELOPMENT

1. In 1957 Rock Island Arsenal developed an experimental Firing Platform T9 which adapted to the 155mm Howitzer Carriage, M1A2. This platform provided a pivot for 360° off-carriage traverse and served as an anchor during firing. It was tested under simulated firing conditions using the water projectile, and on two soil types which were considered average and above average with respect to ground resistance. The firing platform was provided with six (6) drive stakes and short grousers that had six (6) inches soil penetration and fitted to the platform in form of a "cookie cutter" geometry.

2. The Firing Platform T9 did not provide the firing stability required for field use.

3. Reference: RIA Technical Report 58-1799, "Determining Firing Platform Stability for the 155mm Howitzer Carriage, M1A2."

SCALE MODEL TESTS

1. During 1958 model tests were conducted in a sand box to determine the resistance of various firing platform geometrics under controlled design parameters and force environment in both the static and dynamic condition.

2. The results were an evaluation of force and displacement measurements which indicated the order of performance of each of the models.

3. Reference: RIA Technical Report 58-2022, "Determining Firing Platform Stability with Models in a Sand Box."

ARMOUR RESEARCH CONTRACT

1. In 1959 Armour Research Foundation was awarded Contract DA-11-022-508-ORD-2582. This contract covered a design study for the development of a firing platform for towed field artillery carriages of the 105mm and 155mm Howitzer types and force levels.

2. Some of the design concepts included:

a. A vacuum type firing platform model was built and tested on a spring gun type force generator which was a distorted model scaled 1/7 geometric and 1/49 dynamic to the 155mm Howitzer Carriage M1A2. The vacuum platform did not work on sand, snow, ice, soil with grass cover, or wet clay loam. It did work, however, on smooth concrete, brick pavement, and dry clay loam.

- b. A vacuum blanket.
- c. Secondary recoil devices.
- d. Rack and pinion type carriage mounting.
- e. Crawler track carriage mount.
- f. Pneumatic anchor that operates similar to a pile anchor.

3. Reference: Armour Research final report, "Development of a Firing Base for Towed Field Artillery," dated February 1959.

ARSENAL PROTOTYPE DEVELOPMENT

1. During 1960 the model geometries which looked most promising in the sand box tests were redesigned by Rock Island Arsenal into distorted 1/7 geometric scale 155mm Howitzer Carriage, M1A2 size and adapted to Armour's spring gun. Some of the interesting results included the movement of the models during firing, especially rebound conditions. These tests also provided interesting information on the operation of Armour's vacuum platform, especially on wet soils, snow, and ice. In these conditions the platform absorbed the moisture from the soil to such an extent that the vacuum pump became inoperative.

SOUTHWEST RESEARCH DEVELOPMENT

1. In 1960 Southwest Research Institute was awarded Contract No. DA-11-070-21X4992.508-ORD-924. This contract was similar to Armour Research Foundation's contract in that it was for the development of a firing base for towed field artillery carriages of the 105mm and 155mm Howitzer Carriage M2A2 and M1A2 force levels respectively.

2. The design concepts were classified into four (4) main anchor classifications: the horizontal plate, the vertical plate, the pile, and the anchor. Under each of these classifications the contractor listed related concepts.

3. The contractor also conducted an analytical study to define the ground resistance of the four main anchor classifications with respect to the Land Locomotions Laboratories system of soil classification.

4. It was the Southwest Research Institute's conclusion that the pile anchor along with a drilling rig, which would be auxiliary equipment, was the most feasible means for providing firing stability for the 155mm Howitzer

Carriage M1A2. In anchoring the 105mm Howitzer Carriage M2A2, the pile was selected along with another solution that included a horizontal plate fitted with short grousers, which was placed at the middle of the trails.

HARVEY-ALUMINUM DEVELOPMENT

1. Also during 1960 Harvey Aluminum, Research & Development, was awarded Contract DA-04-495-1395. This firing platform investigation was part of a general feasibility type contract for investigating and concepting artillery problems at the 105mm force level. The contractor presented a concept which included a round "pin cushion" type platform that had fifty (50) pins, two (2) inches in diameter around the perimeter of the platform. The ground penetration of the pins was six (6) inches and they could be emplaced and displaced by hydraulic means.

2. Reference: Report "Description of Test Model of a Firing Platform" dated 17 June 1960.

ROCK ISLAND ARSENAL PROTOTYPE DEVELOPMENT

1. During 1961 full scale firing platforms were built by Rock Island Arsenal from the information received in prior model studies and contracts. These platforms were tested on the non-prototype new lightweight 105mm Howitzer Carriage XM102. A description of the platforms and results of the testing follows:

a. "Iron Cross." A pivot float with four outriggers and two grousers on each outrigger. The grousers were thirty (30) inches long, five (5) inches wide, and six (6) inches deep. The grousers were very hard to emplace on frozen ground. During testing only two inches of penetration could be obtained after fifty blows of a ten pound sledge hammer. In partially frozen weak frictional soils (ash fill) the grousers did not provide firing stability at 0° elevation. The outriggers also presented interference with the breech during high angle fire.

b. Cable and Dacron Strap Anchorage. This anchoring arrangement initially included eight (8) cables equally spaced around the perimeter of the conventional platform and tied to drive stakes placed approximately fourteen (14) feet from the platform. After repeated testing and failure with 1/4 to 3/8 inch diameter cables, eight (8) dacron straps 1/4 inch by 2-1/2 inch wide were substituted. The dacron straps also did not prove successful. Both the cables and straps had an inherent problem which was due to their elasticity. This condition allowed the weapon to translate and rebound excessively, which affected the recoil mechanism, especially the counter recoil and the safety of the gun crew.

c. Rear Float Grousers. Eight grousers each three (3) inches wide, four (4) inches long and five (5) inches deep were placed on the rear float in various combinations. It was observed that the addition of grousers on the trail float increased the tendency of the firing platform to hop, which in turn pulled the drive stakes out of the platform.

d. Conventional Platform with Stakes. The conventional nonprototype platform is 47 inches in diameter stakes, eighteen (18) inches long. The platform was fired on weak frictional soils with four stakes emplaced. It was noted that after eleven (11) rounds general ground failure occurred. When eight (8) platform stakes were emplaced, general ground failure occurred after thirteen (13) rounds. The results would indicate that the added stability of using more than four (4) platform stakes in weak frictional soils is small.

e. Pile Anchor. This platform included a circular platform with a tube eight (8) inches in diameter and thirty (30) inches long extending downward to form a pile. The testing of this platform was conducted to check Southwest Research Institute's recommendation. The pile was very difficult to emplace and did not provide the firing stability of the conventional platform with drive stakes.

f. Lip-Type Stakes. The lip-type stake is a conventional drive stake with a plate welded to the top of the stake, which gives it the grouser effect. The lip stake had a tendency to pivot on the lip and pull out of the ground. The conventional stake had more of a tendency to stay in the ground and move with a plowing action.

g. Conclusions. The conclusions reached at the completion of the test are as follows: The conventional platform with drive stakes provides the most practical means known at this time for anchoring a 360° off-carriage traverse artillery weapon. Determining the number of drive stakes needed for firing stability will depend on the time required for emplacement, soil conditions, and the firing stability required. In weak frictional soils four (4) drive stakes provide approximately the same firing stability as eight (8) stakes in the direct fire role.

h. Reference: Rock Island Arsenal Report (Internal), Non-Prototype 105mm Howitzer XM102, dated 13 February 1961.

INTERIM DESIGN FIRING PLATFORM

1. During 1961 Rock Island Arsenal also built an interim firing platform that incorporated new design features over the original nonprototype platform. This platform was tested in the mud of the mobility test area and on the dry grass-covered sandy ash-filled loam at the proving ground. The new features on the platform included: new lightweight box-type construction drive stake retainers that enabled the stakes to be pinned to the platform during firing, removable drive stake retainers which will enable both three (3) inch and four (4) inch diameter drive stakes to be tested, drive stakes with removable heads and adapters for attaching dacron straps to the platform.

2. The first series of tests were conducted in the mud and the following was concluded:

a. The four (4) inch diameter stakes, which are 22 inches long, offer greater resistance than the three (3) inch diameter stakes; however, on the dry ash-filled sandy loam the resistance is about the same.

b. In the mud at 0° elevation greater stability is obtained without the use of grousers; however, at 45° elevation the reverse is true.

3. In the second series of tests on the dry ash-filled sandy loam of the proving ground it was concluded that:

a. The eight (8) two (2) inch deep platform grousers offered greater weapon stability and ground resistance than the 3-1/2 inch deep grousers. It should be noted that the 3-1/2 inch deep grousers would only enter the ground about 1-1/2 inches.

b. Comparison tests were conducted to determine the firing stability of the weapon with 3-1/2 inch grouser and no grousers. It was observed that the eight (8) 3-1/2 inch deep grousers offered a 60% improvement in weapon stability at 30° to 35° elevation, at 45° elevation the improvement was 100%.

4. It should be noted with respect to the overall spectrum of soils that grousers do improve firing stability at high angle fire both on wet and dry soils. The optimum depth of grouser being approximately 2-1/2 inches. It should be noted, however, that when grousers are used on a platform and the platform is carried beneath the bottom carriage, a serious mobility problem exists. This problem is that grousers function as a plow in deep rutted roads rather than a skid as they would if they were removed.

FUTURE INVESTIGATIONS

1. A study of the hazards to personnel and equipment, arising from the use of explosives, is in progress. A matter of some concern, is the possibility of premature detonation of electric blasting caps by R. F. energy. A near term projection of further study, urges testing to determine the degree of sensitivity to these transient currents.
2. Searches will be undertaken for a suitable non-electric substitute, fulfilling the function without excessive time penalties for set up and firing. A continuing alertness to well reasoned solutions to the Arctic staking problem shall be maintained.
3. Further studies on the firing platform for Artillery Weapons and on Anchoring studies in general for temperate conditions are to be conducted on a continuing basis. Technical Notes and/or Reports covering any significant findings of future work will be published.

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This report outlines the principal approaches tested and/or evaluated for emplacement of anchoring devices for rocket launchers and artillery carriages. Part I deals with the anchorage program of rocket launchers in hard frozen ground. Part II covers the investigation of stability problems of firing platforms for conventional cannon-type artillery weapons in temperate climates. Critical anchoring problems in both Arctic and temperate climates exist for both types of weapons.

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